Muon Colliders Parameters

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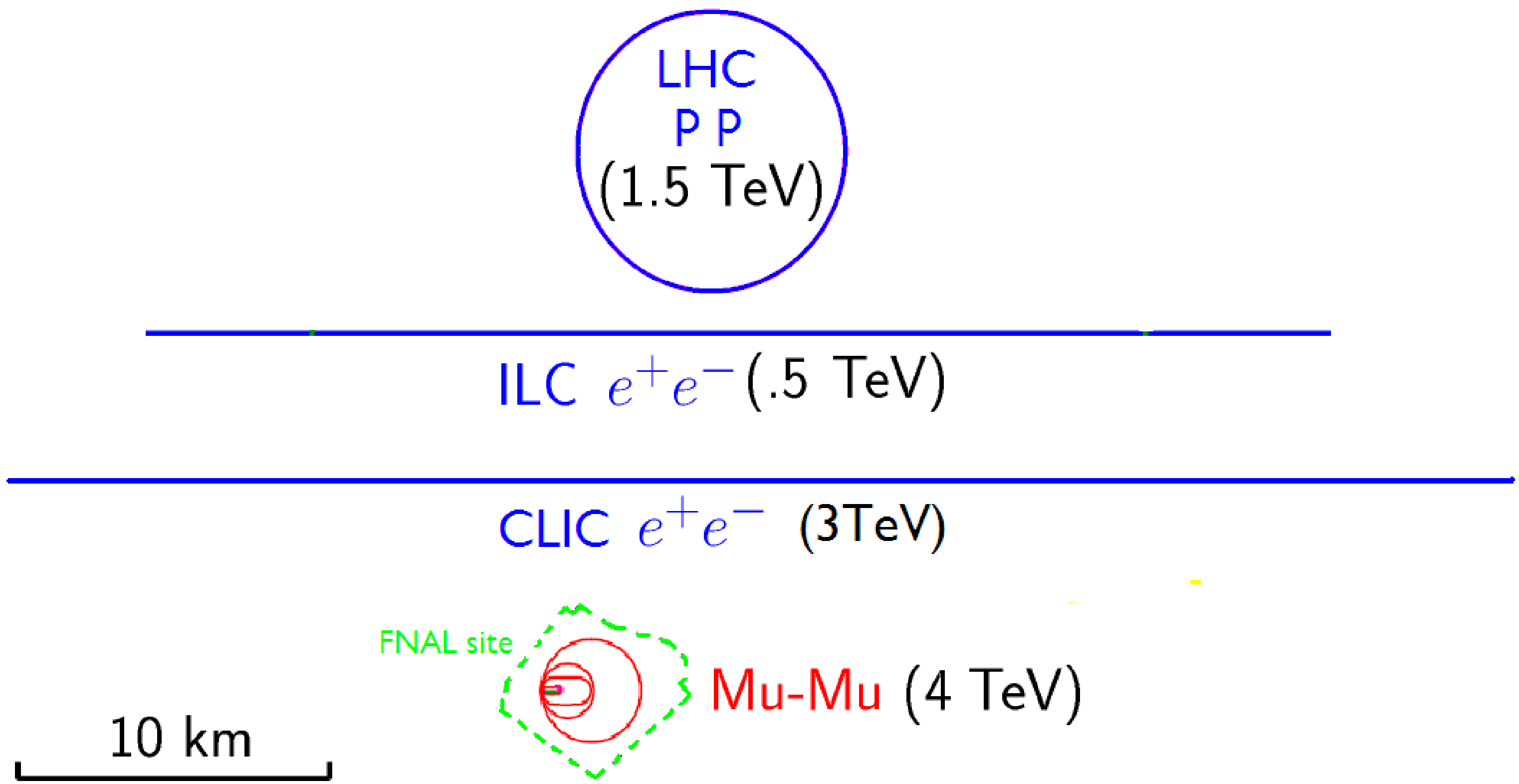
MAP Winter Collaboration Meeting

SLAC

3/8/12

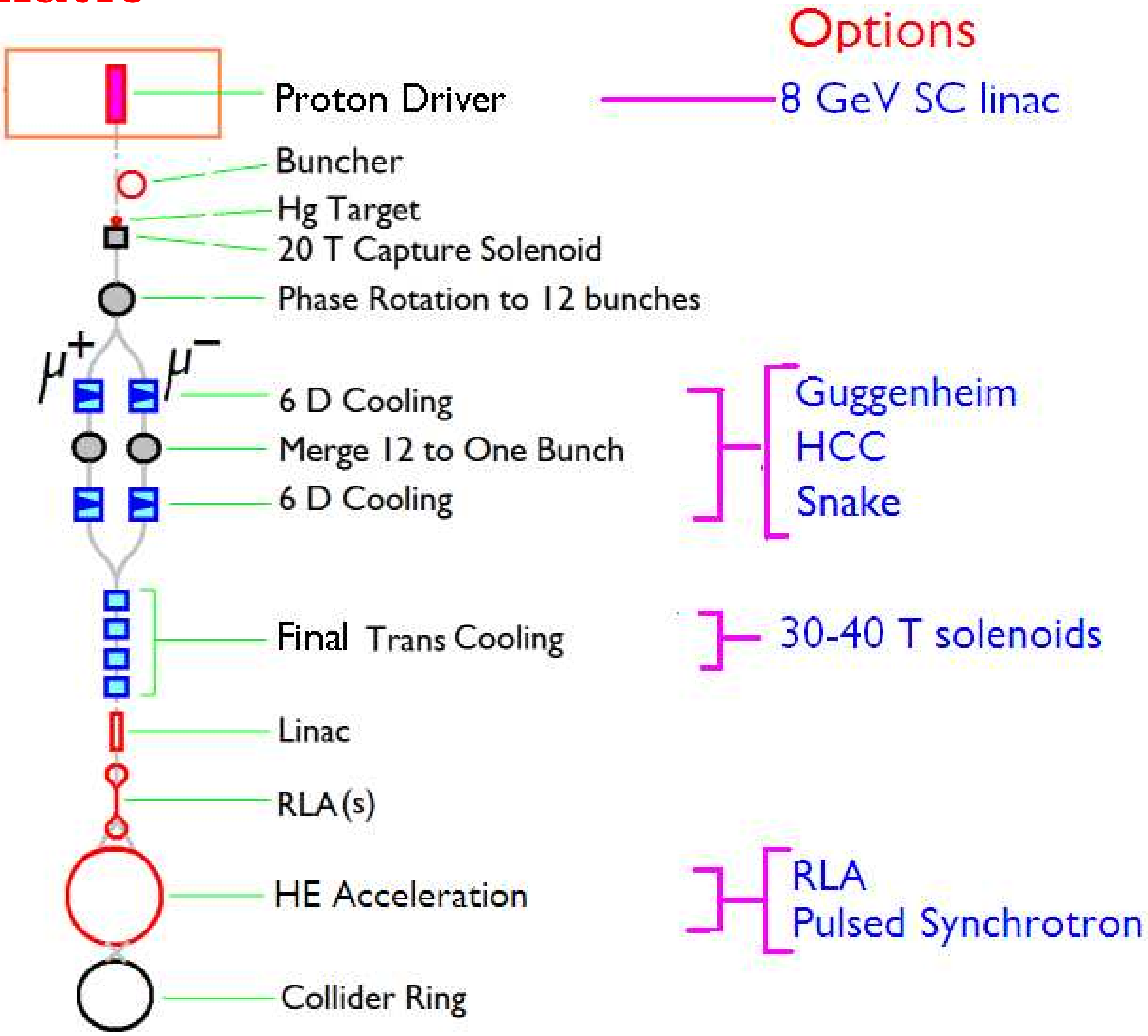
- Introduction to scheme
  - Proton Driver
  - Target and phase rotation
  - Cooling (including space charge)
  - Acceleration
  - Rings (including ν radiation)
- Power consumption & CLIC comparison
- Conclusion

Introduction



- Muon Colliders certainly smaller,
- Use less power ?
- Cheaper ??

Schematic



Options
Proton Driver
8 GeV SC linac
Buncher
Hg Target
20 T Capture Solenoid
Phase Rotation to 12 bunches
μ^+
μ^-
6 D Cooling
Merge 12 to One Bunch
6 D Cooling
Guggenheim
HCC
Snake
Final Trans Cooling
30-40 T solenoids
Linac
RLA(s)
HE Acceleration
RLA
Pulsed Synchrotron
Collider Ring

Parameters

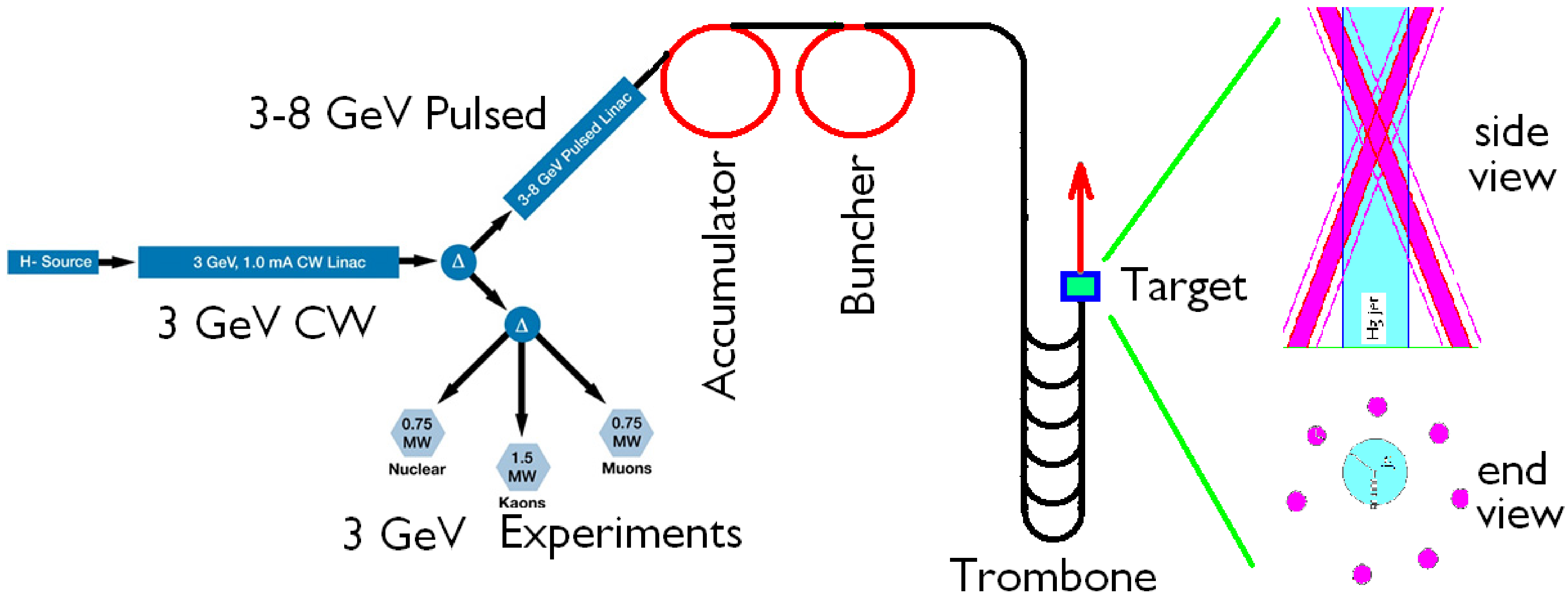
C of m Energy	1.5	3	6	TeV
Luminosity	1	4	12	10^{34} cm^{2}sec^{-1}
Muons/bunch	2	2	2	10^{12}
Muon Trans Emittance	25	25	25	pi μm
Muon Long Emittance	72,000	72,000	72,000	μm

- These have been stable for some time
- But there are some problems only now being addressed:

- Space charge effects
- Allowances for emittance dilution in Acceleration
- Requirements for Super-conductors in 6D cooling

I will step through the major systems, but spend most time on Cooling

Proton Driver e.g. Project X

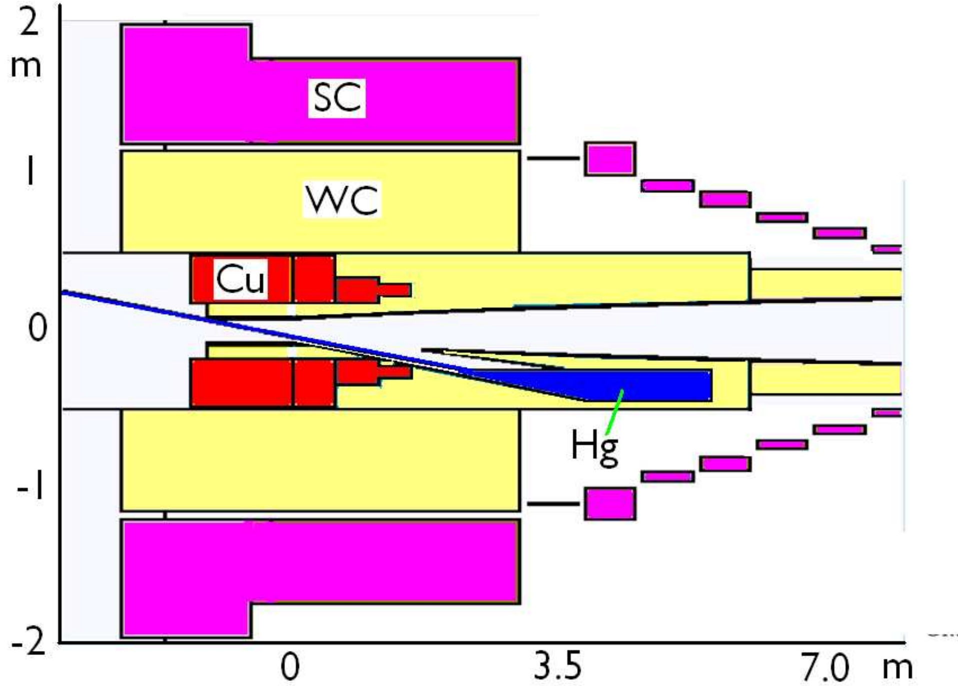


New Task Force on Project X upgrades Gollwitzer

- Upgrade CW linac to 5 mA
- 3-8 GeV Pulsed Linac
- Accumulator, Buncher, and Trombone (Ankenbrandt)

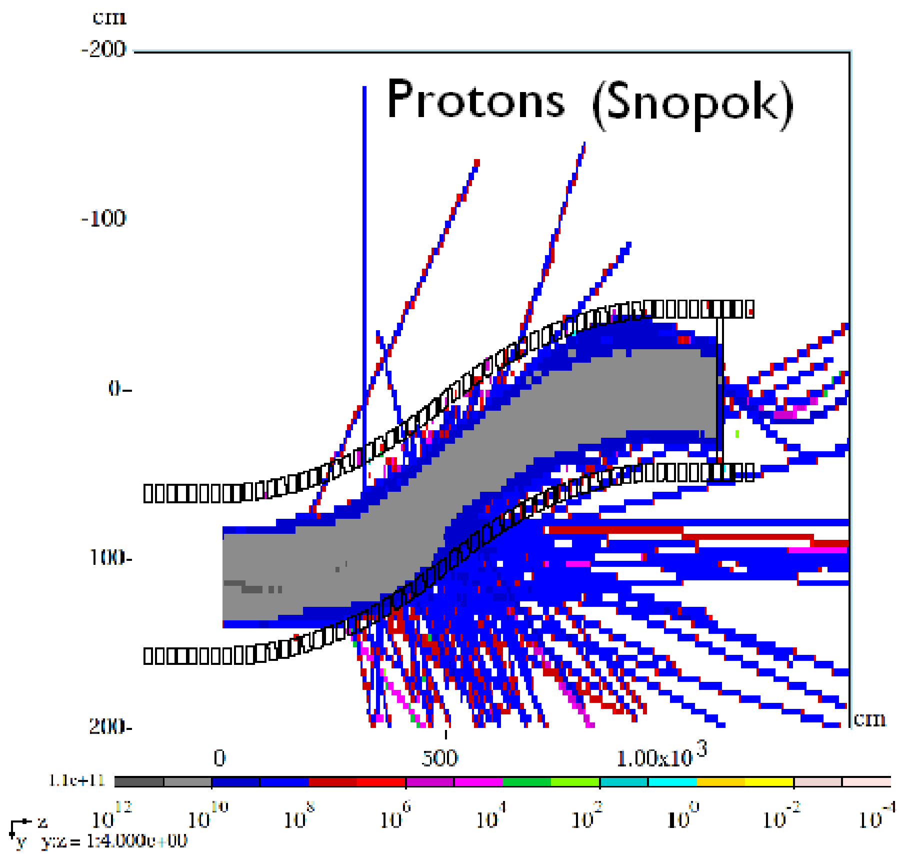
Target & Capture

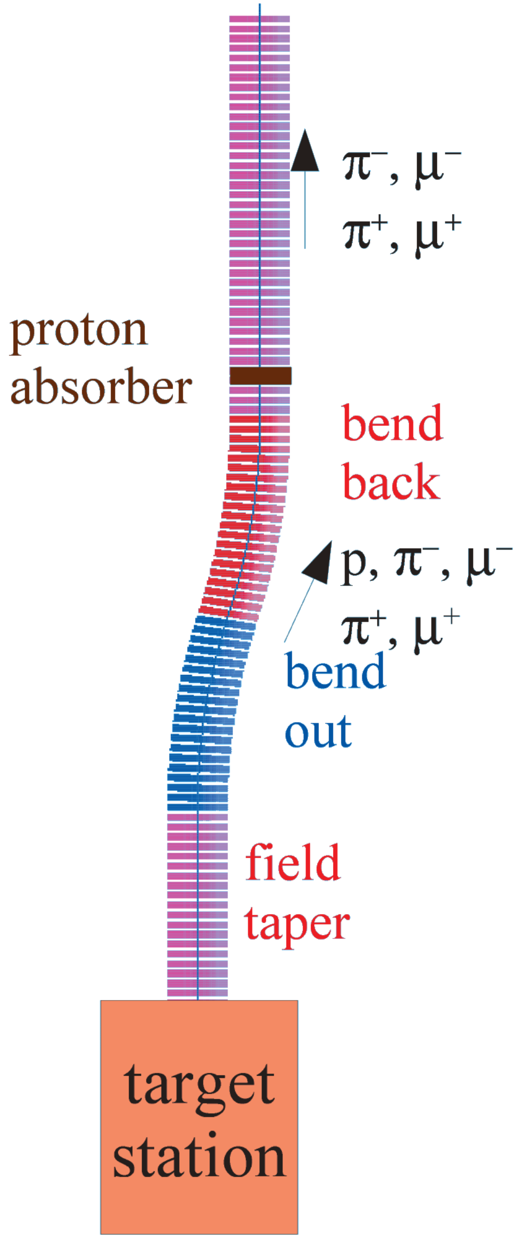
New 20 T Hybrid with increased Shielding



- Copper coil gives 6 T,but uses 15 MW of wall power
- Super-conducting solenoid give 14 T, tapering to 3 T, but has huge stored energy
- Tungsten Carbide in water shielding for 4 MW 8 GeV beam
- Considering a smaller bore all superconducting magnet with lower field (eg 15 T)

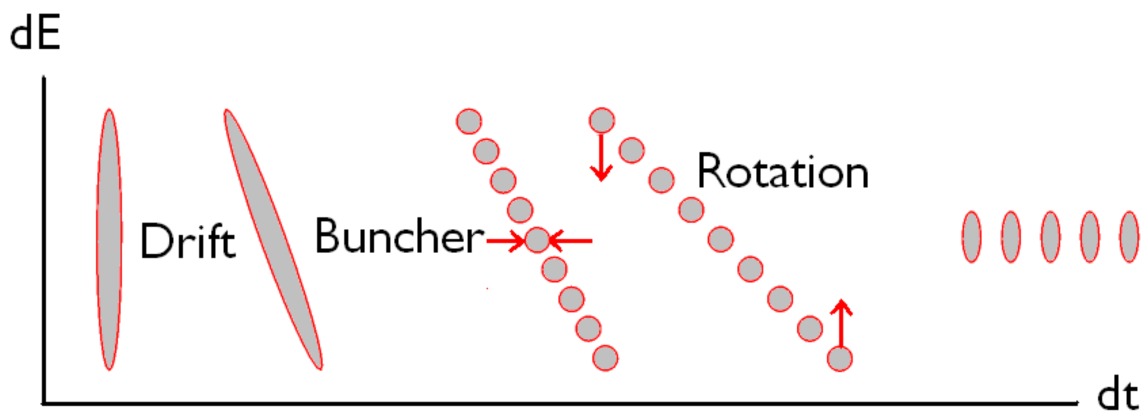
Design of a Chikane and absorber

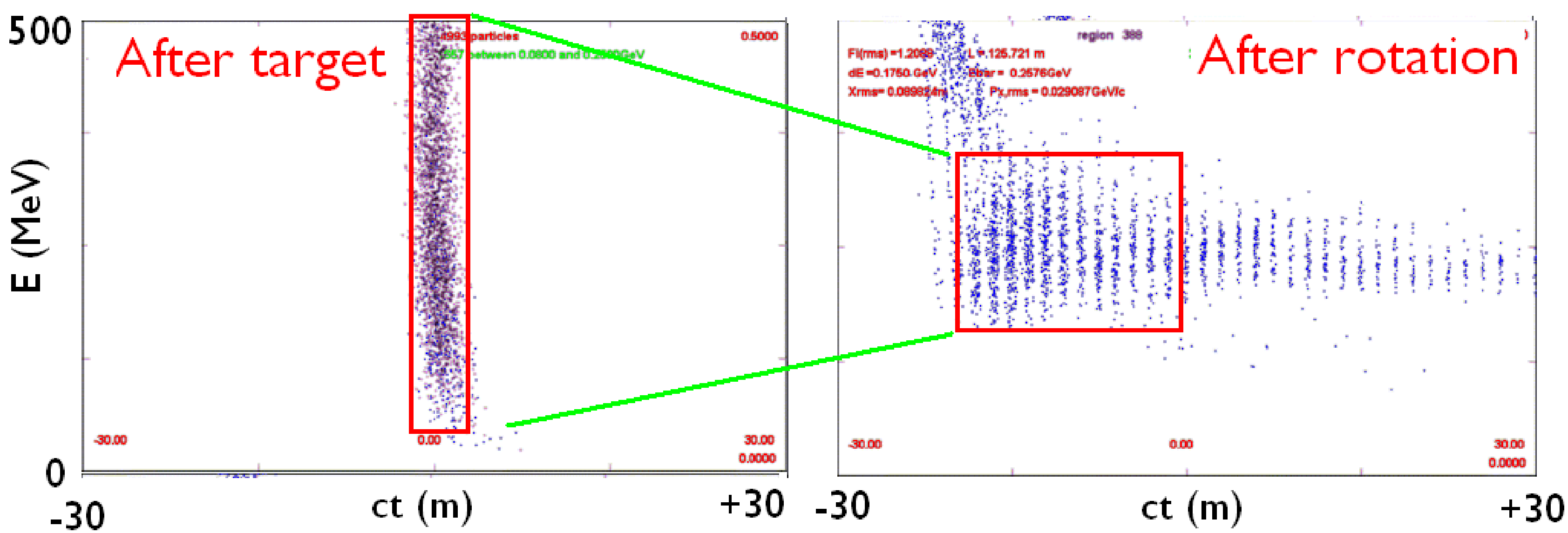




- Greatly reduces unwanted proton and electrons passing down channel and heating superconducting components
- Lowers cryogenic load and needed wall power

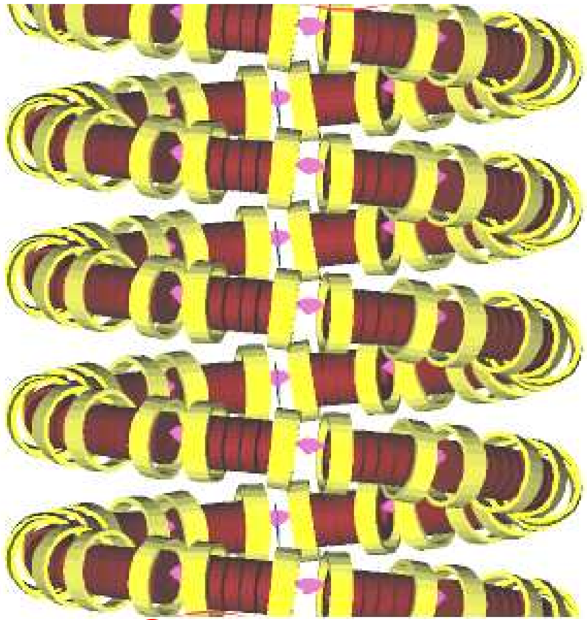
New Phase Rotation→12 bunches (Neuffer)



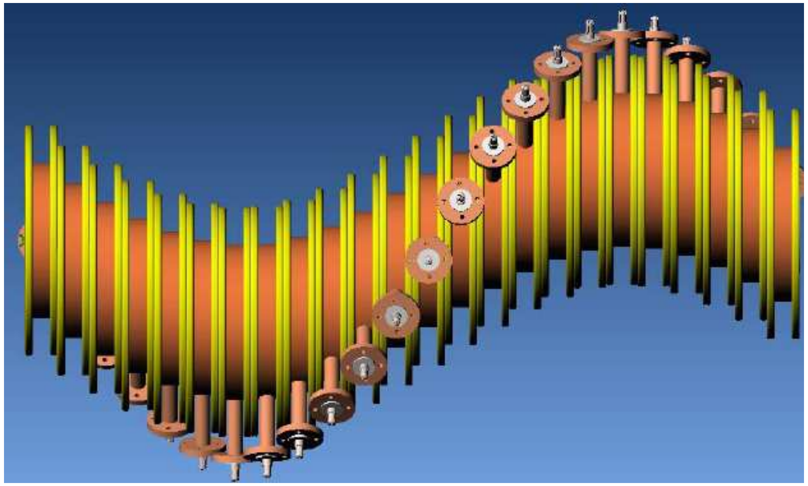


- Good efficiency into just 12 bunches

3 candidate 6D cooling lattices

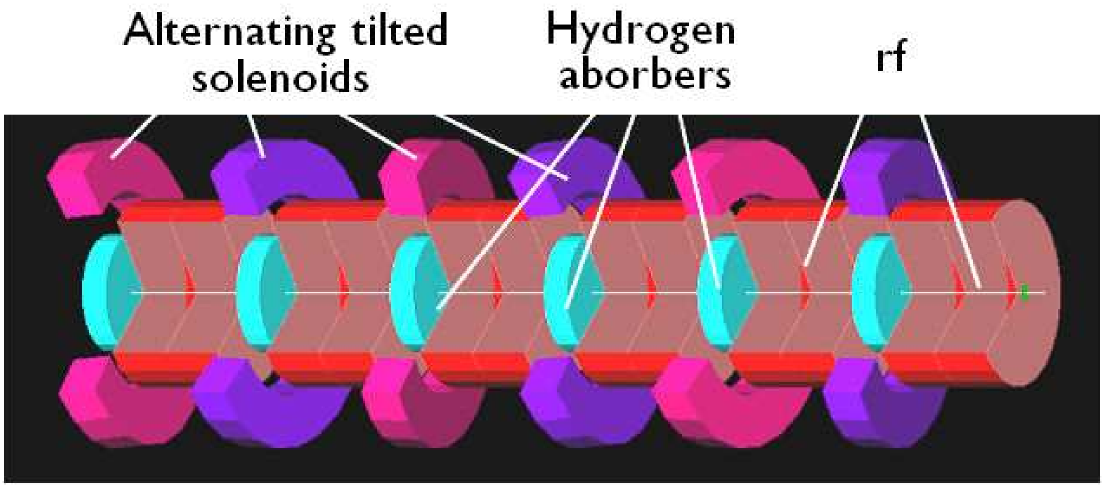


Guggenheim



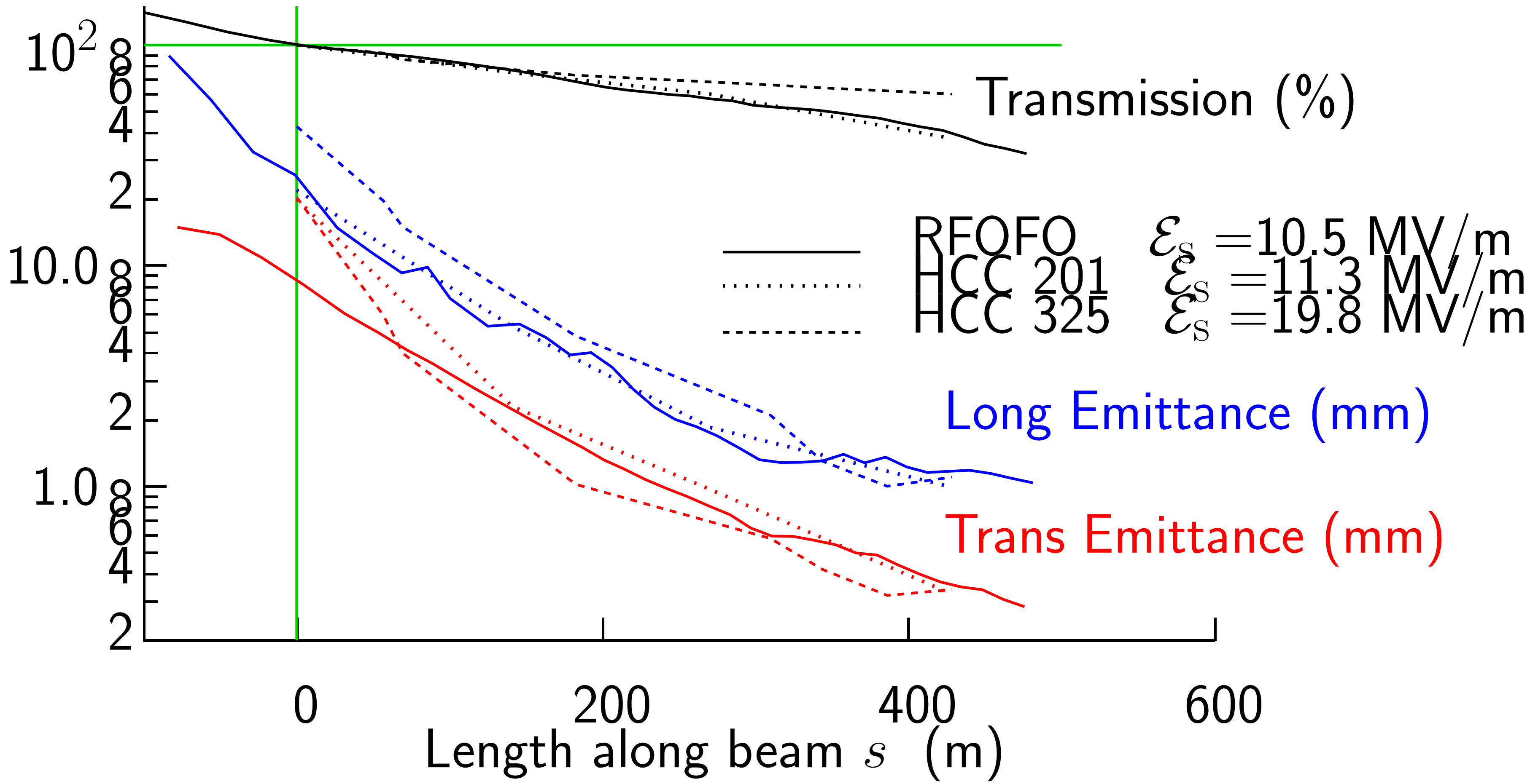
Helical Cooling Channel

Snake



- All simulated   All have challenges

Guggenheim and HCC Performances



- Emittances are vs. length along the beams (not the helix axes)
- Cooling rates similar
- Transmissions similar for similar gradients,

Guggenheim Advances since JLAB Meeting

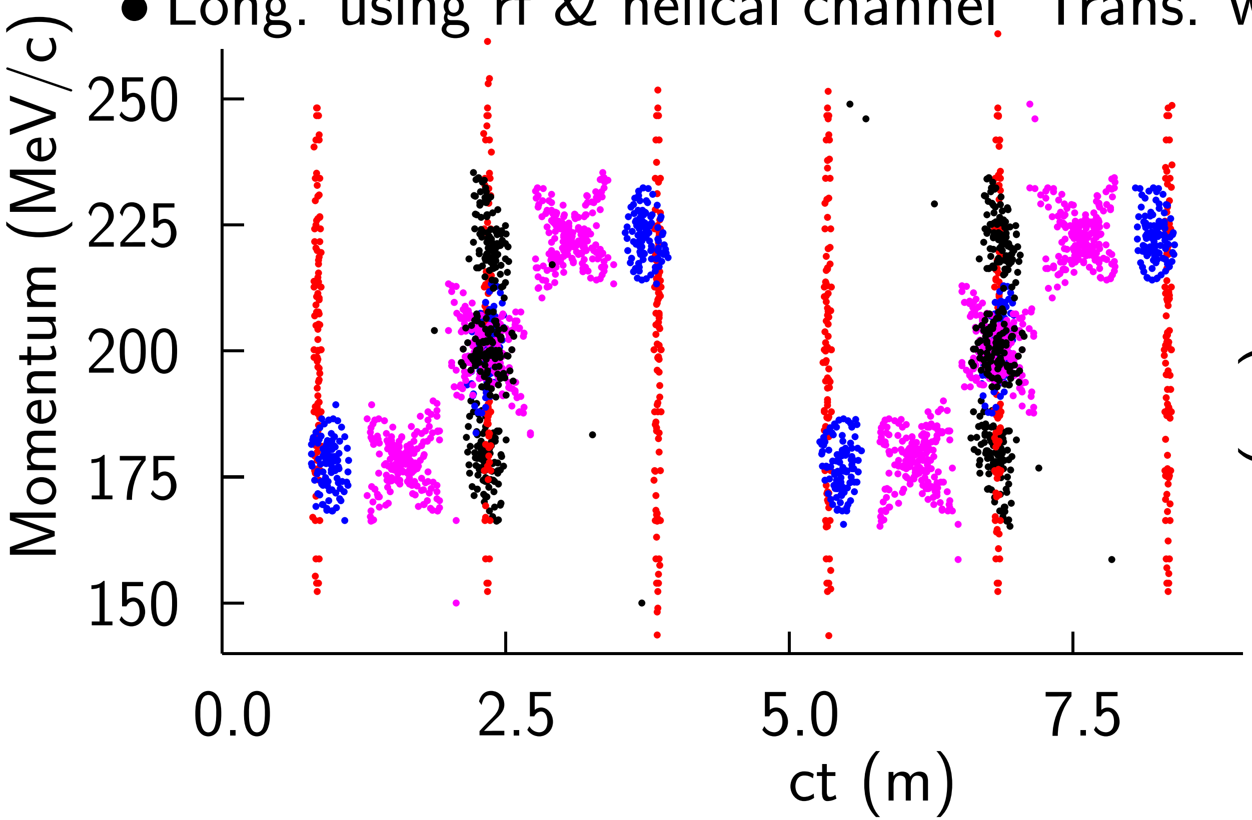
- 6D Merge from 12 to 1 bunch   Now using Helical Channel

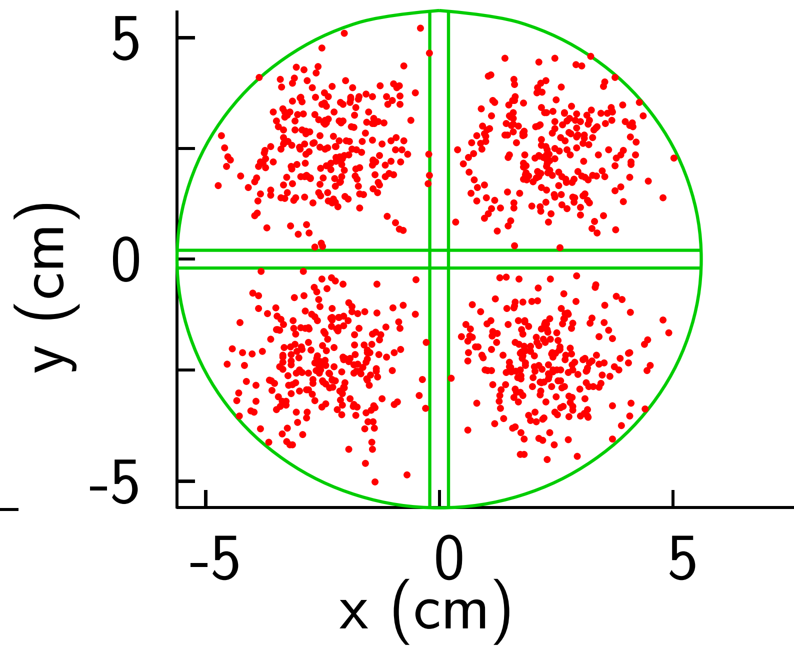
- Use of Non-flip (Fernow) lattices to ease conductor requirements
- Weakened emittance exchange to ease longitudinal space charge
- Adding new stage to get back to Final Cooling sequence
- Then adding HTS non-flip lattices to cool to lower emittances

- Redesign Final Cooling Sequence giving allowance for dilutions and increased focus in transports between stages for space charge

New 6D Merge (A work in progress)

- Long. using rf & helical channel Trans. with trombones



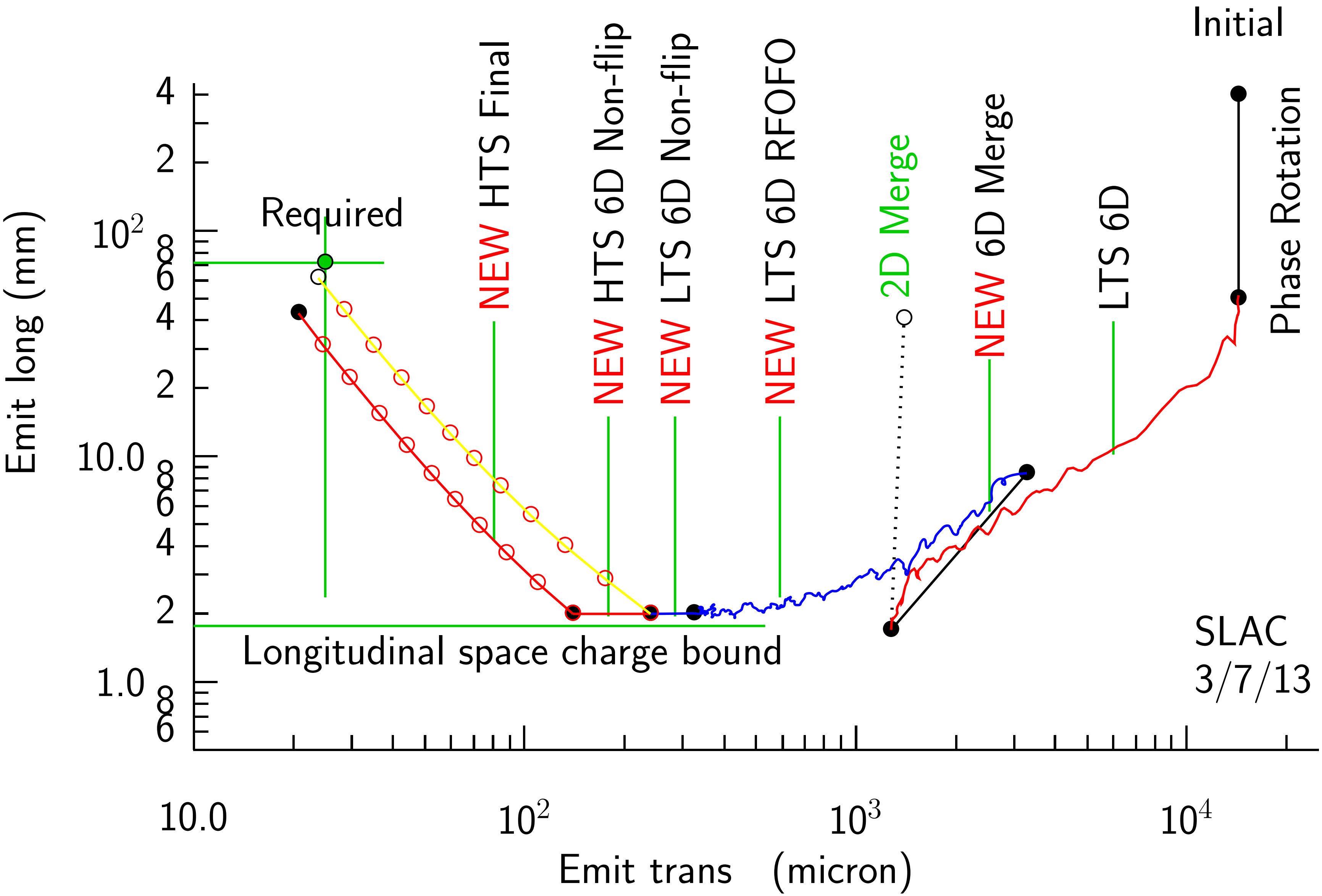


Longitudinal 12→ 4 Transverse 4→1

- $\epsilon_\perp$ 1.7 → 3.38 $\epsilon_\parallel$ 1.28 → 3.29 (μ m) 96%
- Simulation used 60 m Helical channel and unreasonable gradients
- Now reducing gradients and trying simple drift

New (3/7/12) Cooling Sequence

ICOOL Simulations of 6D cooling are for Guggenheim lattices

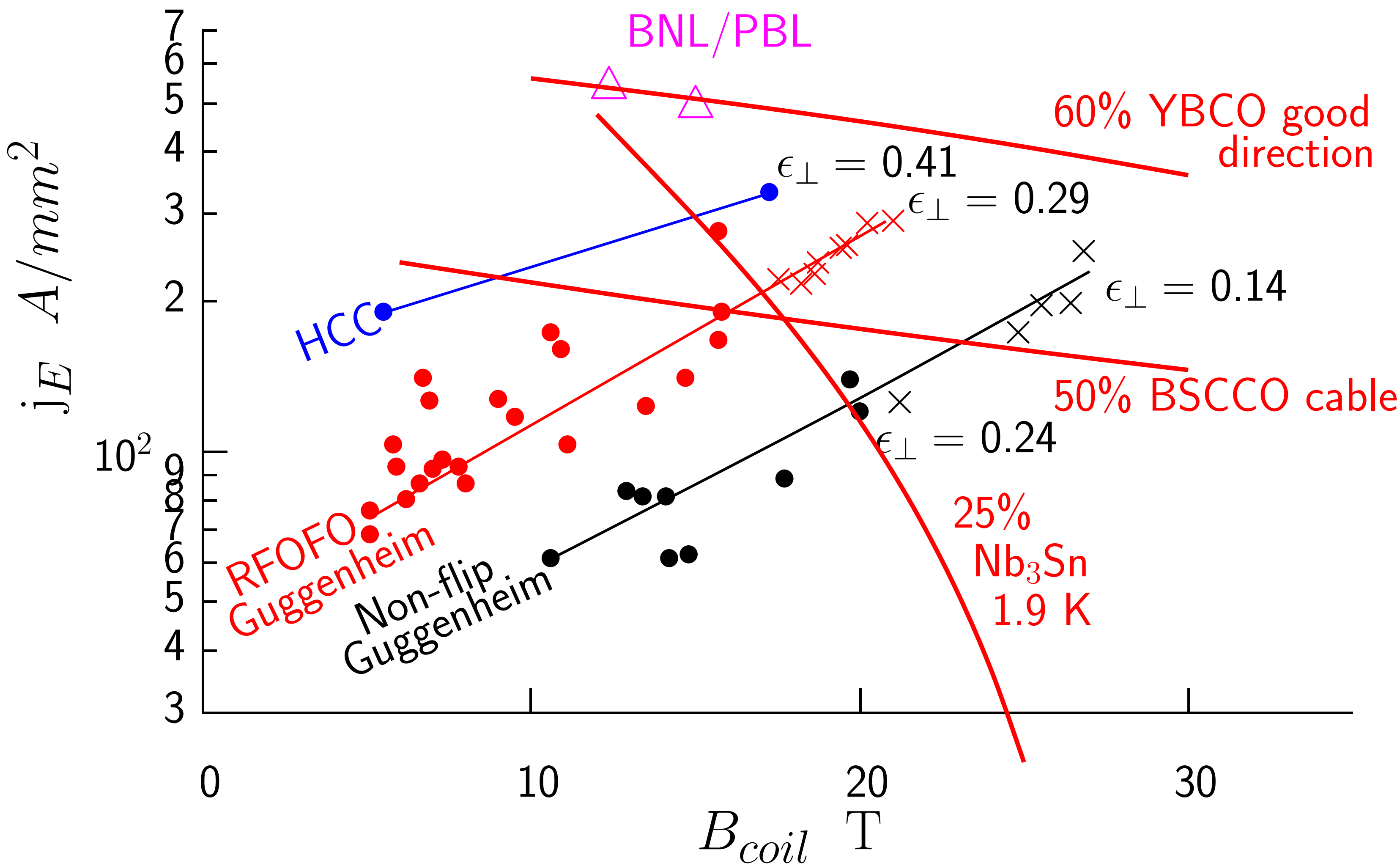


Likely Super-Conductor Performance Limits

- Take 'Engineering current densities' from NHMFL data
- Assume average j_E= 60% of YBCO tape, as achieved in BNL/PBL test coils
- Assume average j_E= 25% of Nb_3Sn, allowing for stabilizer & ss support (Bob Weggel 15 T design)
- Assume average j_E= 50% of BSCCO, assuming need for ss support, but no additional stabilizer

- These will be somewhat conservative because they assume uniform density based on highest field

6D cooling Conductor requirements



- indicates hopes for Nb_3Sn conductor

$\times$ indicates need for HTS

Discussion of Super-conductor requirements

- Current HCC designs require high current densities
- HCC designs to cool below 0.41 mm will need HTS

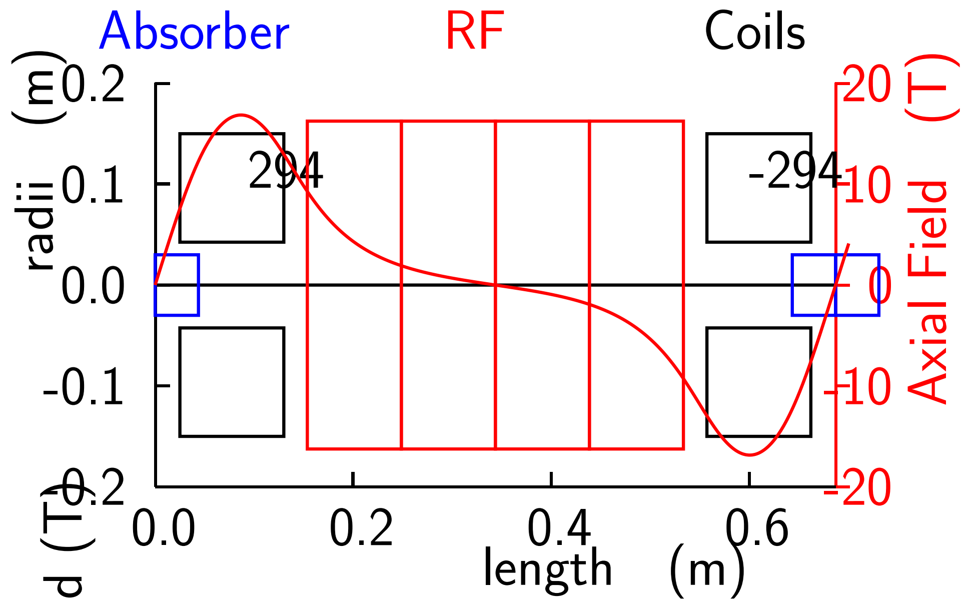
- Later RFOFO lattices have specs beyond Nb_3Sn

- But non-flip (wait) lattices can get to $\epsilon_\perp$=0.24 mm with Nb_3Sn
- And non-flip can get to lower $\epsilon_\perp$ (e.g.0.15 mm) with YBCO

Non-flip vs. RFOFO Lattices

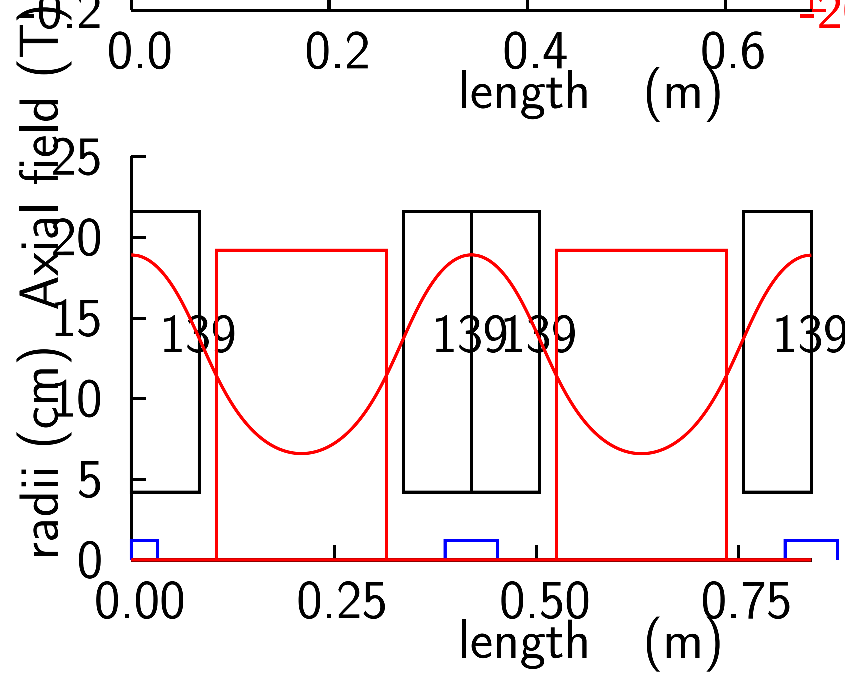
Normal RFOFO

B(rf)=6 T



Non-Flip lattice

B(rf)=12 T



Lower current densities but higher fields on rf

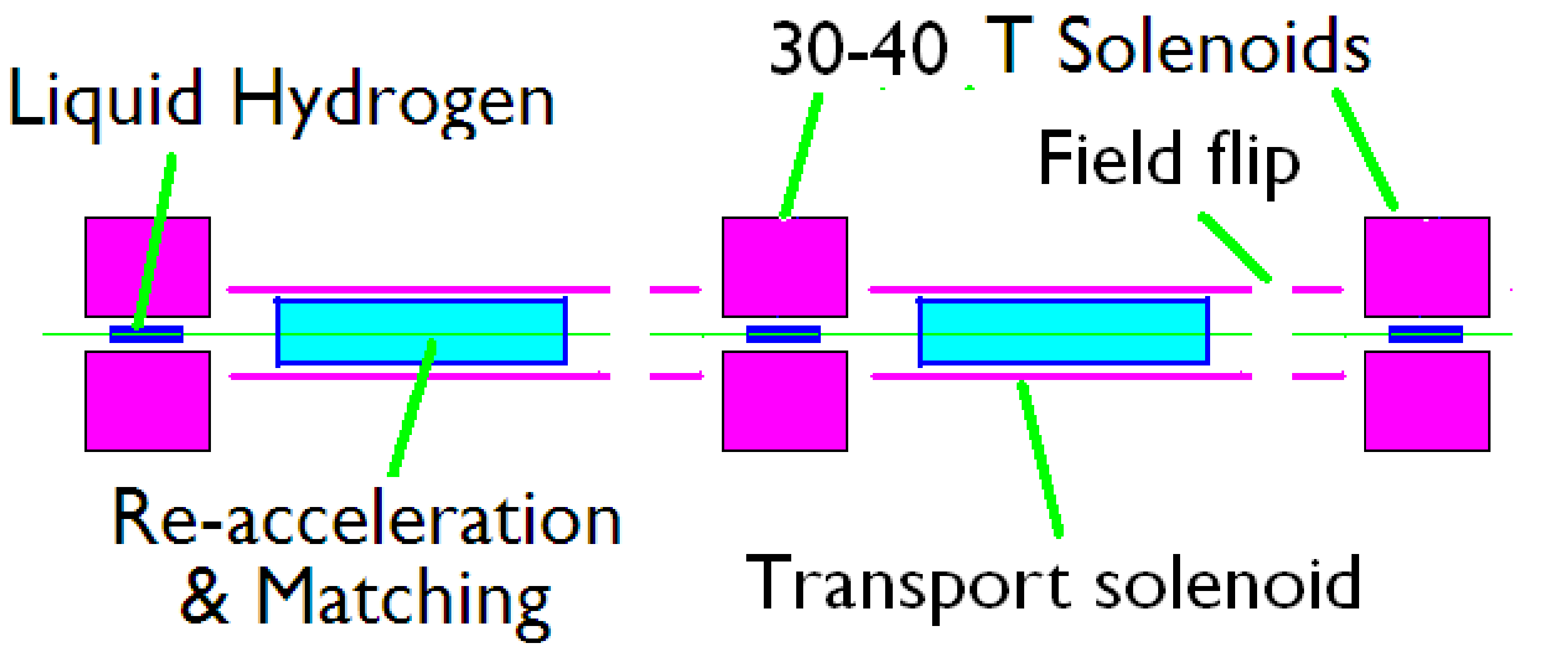
New Non-flip lattices with HTS coils

	cell cm	Mom MeV/c	beta cm	emit mm	L cm	r1 cm	r2 cm	j A/mm^2	Bo T	Bmax T
37h	41.0	200	2.8	0.24	16.8	4.2	21.6	174	23.6	24.7
38h	41.0	200	2.3	0.20	16.8	3.8	18.8	197	24.4	25.3
39h	41.0	200	1.9	0.17	16.8	2.6	17.6	199	26.0	26.2
40h	33.6	160	1.5	0.14	13.4	2.1	14.1	253	26.3	26.6

- Emittances to 0.14 mm now possible
- Conductor parameters are not apparently a problem

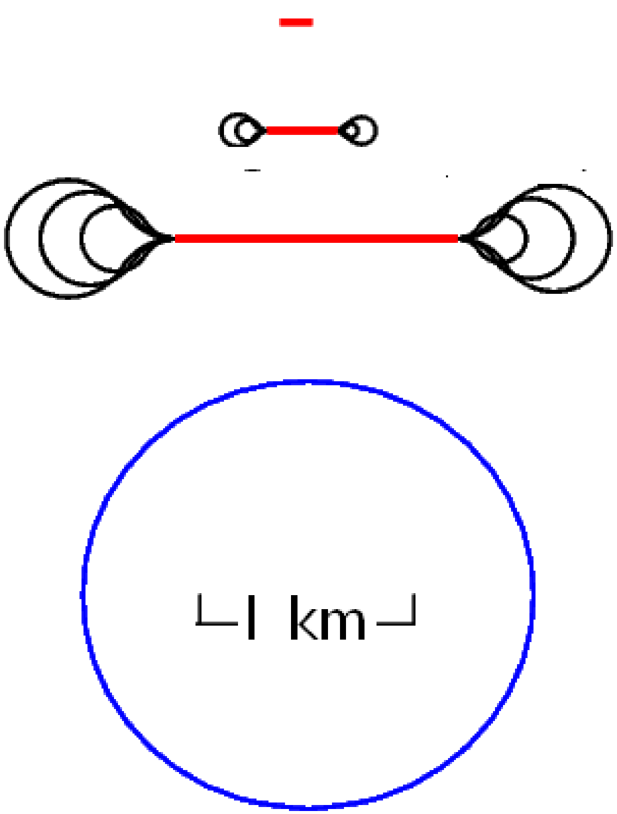
- Fields on rf even higher
- But we do not know if this is bad with Be
- We too should study bucking coils

New Final Cooling to $\epsilon_\perp$=20 μm $\epsilon_\parallel$=43 mm



- Cooling in hydrogen simulated for all 10 stages (was 13)
- Matching and re-acceleration still only simulated last stages
- Consequences of a limitation to 30 T now more acceptable but we believe that 40 T is attainable and leave as baseline

Acceleration

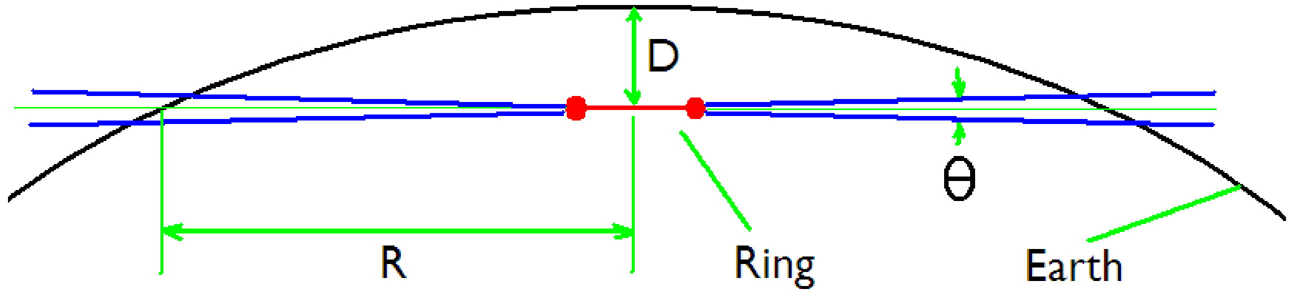


	E GEV		passes	Lengths
1)	.4-1.5	Linac		L(linac)= 68 m
2)	1.5-12.5	RLA	n=4.5	L(linac)= 306 m
3)	12.5-100	RLA	n=6.5	L(linac)= 1250 m
4)	100-400	RCS	n=23	Circ = 6283 m
5)	400-750	RCS	n=27	Circ = 6283 m

both RCS pulsed at 15 Hz

- These specifications and loss estimate have not been updated
- Transmission was 65.2 %, but will be somewhat worse
- Hopefully compensated by improvements in front end & cooling

Neutrino Radiation



$$R_B = 4.4\,10^{-24} \frac{N_\mu\ f\ E^3\ t\ <B>}{D\ B}\ \mathrm{Sv} \quad \text{from regions of uniform B}$$

$$R_L = 6.7\,10^{-24} \frac{N_\mu\ f\ E^3\ t\ <B>\ L}{D}\ \mathrm{Sv} \quad \text{from straight sections}$$

For $R_B = R_L$ $=$ $\boxed{\text{10\% Fed limit}}$ $=$ 0.1 mSv (10 mRad)

E TeV	B(min) T	L(max) m
1.5	0.25	2.4
3.0	1.5	0.28

Yuri Alexahin and magnet designers are making progress here

MC Rings

6 TeV design is my extrapolation for the same ν rad

C of m Energy	1.5	3	6	TeV
Luminosity	1	4	12	10^{34} cm^{2}sec^{-1}
Muons/bunch	2	2	2	10^{12}
Total muon Power	7.2	11.5	11.5	MW
Ring <bending field>	6.04	8.4	11.6	T
Ring circumference	2.6	4.5	6	km
β^* at IP $= \sigma_z$	10	5	2.5	mm
rms momentum spread	0.1	0.1	0.1	%
Depth	135	135	540	m
Repetition Rate	15	12	6	Hz
Proton Driver power	4	3.2	1.6	MW
Muon Trans Emittance	25	25	25	μm
Muon Long Emittance	72	72	72	mm

Note: Muon parameters the same for all energies

Estimated Wall Power Requirement

From summer 2011

	Len	Static	Dynamic	—	—	—	Tot
		4^o	rf	PS	4^o	20^o	
	m	MW	MW	MW	MW	MW	MW
p Driver (SC linac)							(20)
Target and taper	16			15.0	0.4		15.4
Decay and phase rot	95	0.1	0.8		4.5		5.4
Charge separation	14						
6D cooling before merge	222	0.6	7.2		6.8	6.1	20.7
Merge	115	0.2	1.4				1.6
6D cooling after merge	428	0.7	2.8			2.6	6.1
Final 4D cooling	78	0.1	1.5			0.1	1.7
NC RF acceleration	104	0.1	4.1				4.2
SC RF linac	140	0.1	3.4				3.5
SC RF RLAs	10400	9.1	19.5				28.6
SC RF RCSs	12566	11.3	11.8				23.1
Collider ring	2600	2.3		3.0	10		15.3
Totals	26777	24.6	52.5	18.0	21.7	8.8	145.6

Discussion

- Recent and discussed reductions
  - Discussion of replacing hybrid 20 T capture solenoids with 15-18 T Nb_3Sn coils removing 15 MW resistive coil
  - Improved shielding around capture reducing losses to 4 deg 0.86 kW$\rightarrow$ 0.46 kW lowering wall power by 200 kW
  - Addition of Chikane should reduce losses in early cooling from 50 kW to say 25 kW lowering wall power 6.8$\rightarrow$ 3.4 MW
- Could reduce total by 18.6 MW

For other energies (including above):

C of mass Energy	TeV	1.5	3	6
Wall power	MW	127	140	180

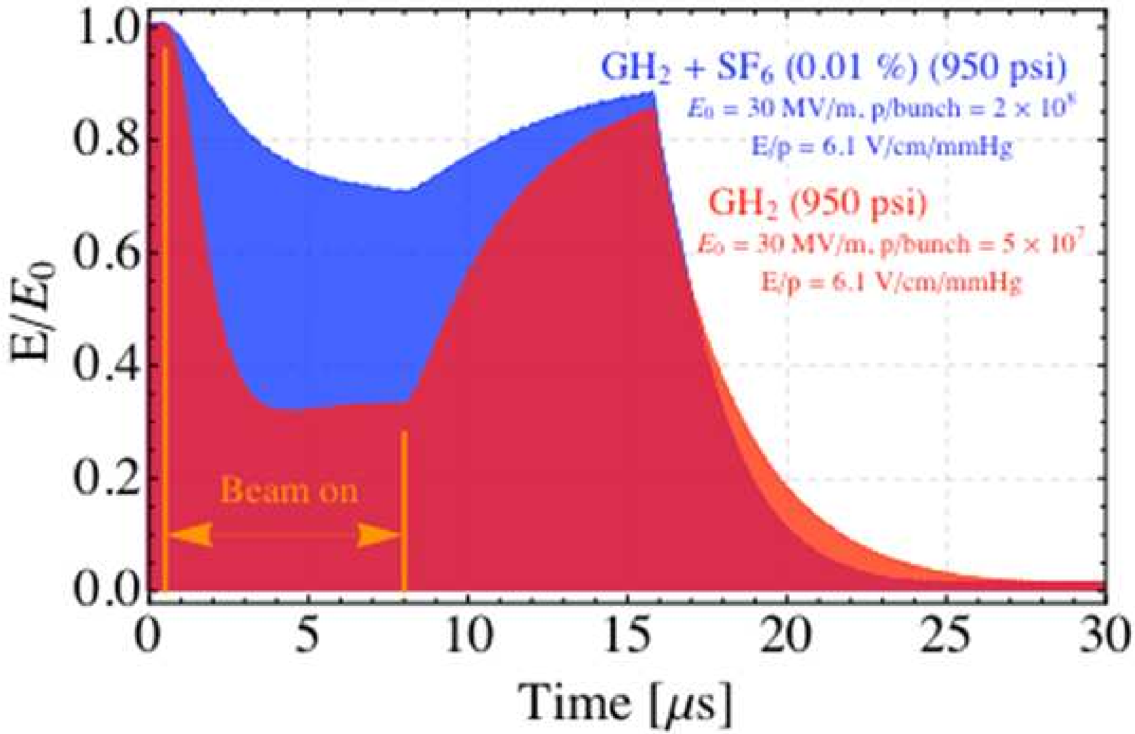
Does not include detectors, buildings, air conditioning etc and is probably optimistic, despite the trend

Compare 3 TeV $\mu^+\mu^-$ with e^+e^- CLIC

		$\mu^+\mu^-$	e^+e^-
Luminosity	10^{34} cm^{2}sec^{-1}	4	2
Detectors		2	1
β^* at IP $= \sigma_z$	mm	5	0.09
Lepton Trans Emittance	μm	25	0.02
rms bunch height	μm	4	0.001
Total lepton Power	MW	11.5	28
Proton/electron Driver power	MW	4	188
Wall power	MW	140	465

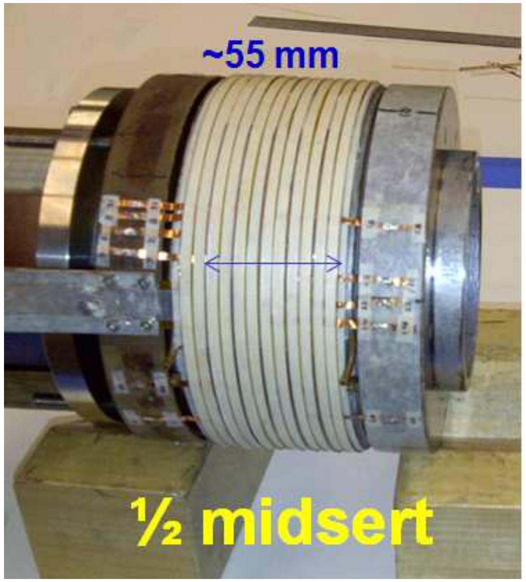
- $\mu^+\mu^-$luminosity twice CLIC's (for dE/E $< 1\%$) & 2 detectors
- Spot sizes and tolerances much easier than CLIC's
- Wall power $\approx 1/3$ CLIC's
- But less developed and needs the Muon Accelerator Program (MAP) $\rightarrow$ Feasibility Study

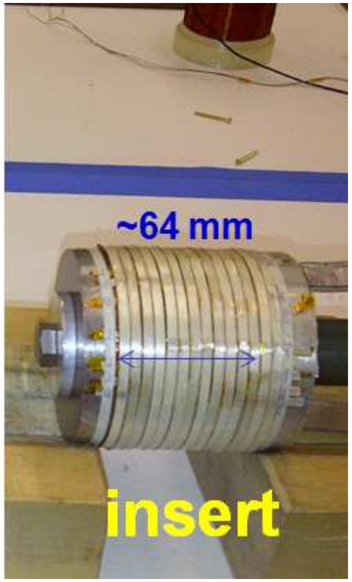
Technology progress:
Progress in High Pressure Gas Cavity in beam tests

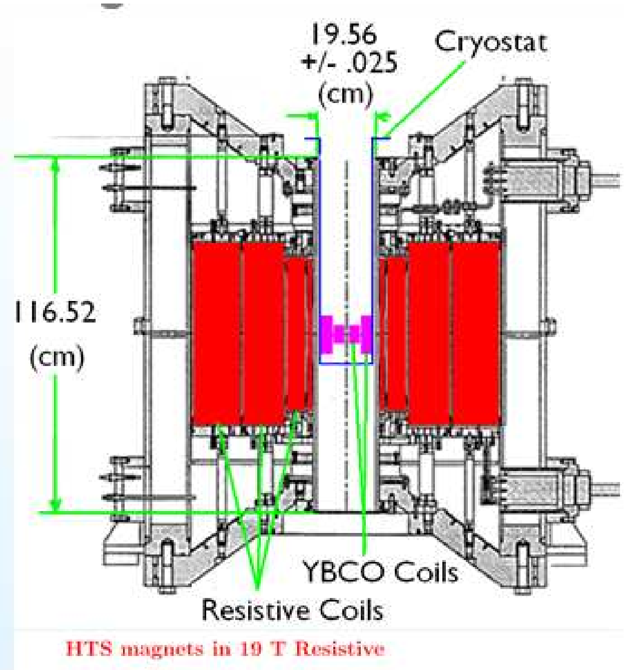


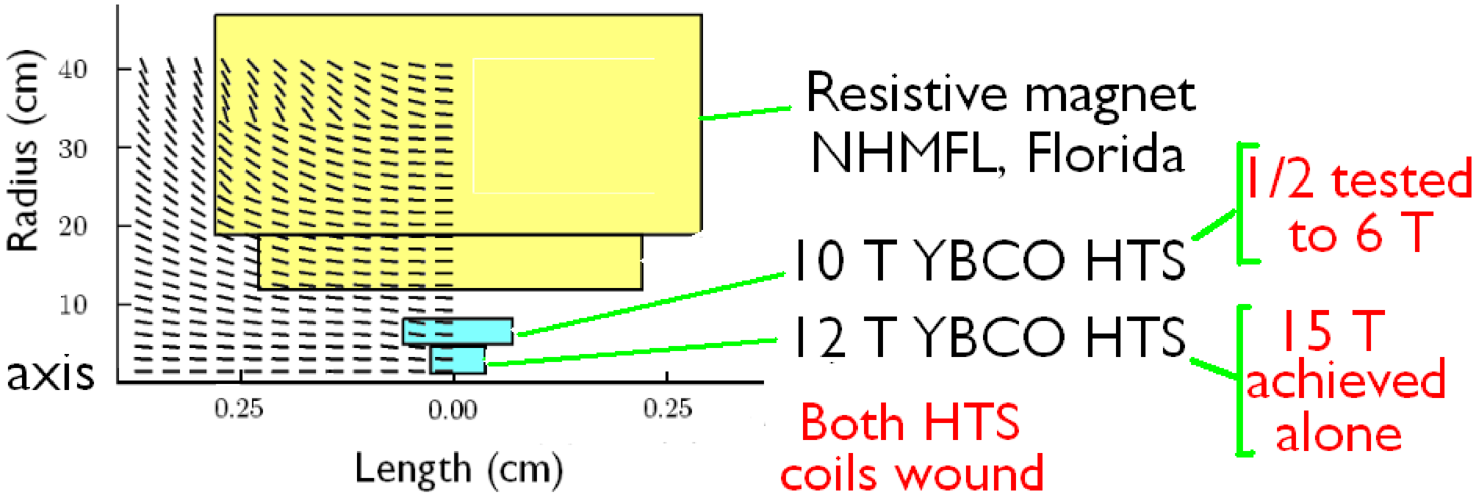
- No breakdown with magnetic field and/or beam
- Beam loading, and effects of electro-negative gas, understood

Progress in HTS magnets by PBL/BNL SBIR









- Expected field later this year $\approx$ 35 T

Progress in rf with magnetic fields

Cipper button
after 28 MV/m
& 3 T

Beryllium button
after 33 MV/m
& 3 T

Clear evidence that Be resists damage in magnetic fields

CONCLUSION

- Much simulation progress this year
  - new capture magnet design, chikane, new merge designs, Non-flip cooling lattices, lower final emittances, detector background studies
  - Space charge problems appear soluble
- Progress in needed technologies
  - In HP Gas cavity in a beam
  - In YBCO coils
  - In rf-in-magnetic fields using Beryllium
- Favorable comparisons with CLIC:
  - Luminosity greater than CLIC's
  - Estimated wall power $\approx 1/3$ of CLIC
- Extrapolation to higher energies thinkable